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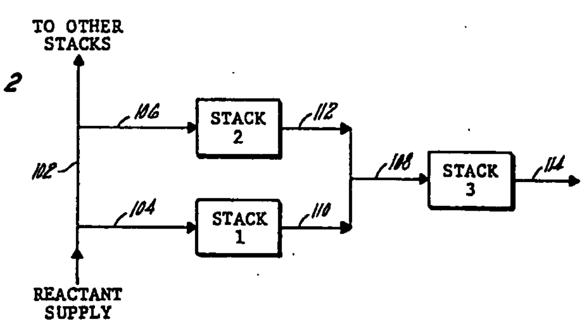
(54) Reactant distribution for multi-stack fuel cell power plants.

(57) The fuel cell stacks in a multi-stack power plant are provided with hydrogen-enriched fuel in serial fashion with the fuel outlet (110; 112; 206; 208) of one or more stacks forming the fuel inlet for a subsequent stack in the series. The fuel can be initially fed into the series via two or more stacks in parallel with the outlets of the parallel stacks being combined and fed serially into the subsequent stacks. Alternatively, the fuel can be fed through stacks which are arranged in a simple series, one stack after another. Fueling the stacks in either aforesaid manner ensures that each cell in the stack will receive an adequate amount of fuel for proper functioning and allows for significant relaxing of cell manufacturing tolerances and resulting economics.

FIG. 2



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Description

Reactant Distribution For Multi-Stack Fuel Cell Power Plants

Technical Field

This invention relates to the fueling of fuel cell stacks in multi-stack power plants, and more particularly to a system whereby each cell in each stack is assured an adequate fuel charge for proper functioning.

Background Art

In order to enable the production of commercially viable amounts of electricity from fuel cells, the cells are arranged in stacks which operate as a unit to provide the desired power. The individual cells in the stack are generally flatly configured and are coaxially stacked and connected electrically in series with the electricity generated flowing in the direction of the stack axis through each cell in the stack, and thence into a DC-to-AC converter. The hydrogen enriched fuel which is used as a source of hydrogen ions and electrons is fed through the individual cells in the stack in a direction transverse to the axis of the stack. Dissemination of the fuel to the cells in the stack is accomplished by means of inlet and outlet manifolds which extend up opposite sides of the stack and which are connected to fuel inlet and outlet pipes.

For the stack to function properly, it is essential that each fuel cell in the stack be provided with sufficient fuel at least equivalent to the current which is forced through it by operation of the other cells in the stack. It is axiomatic that uniform fuel supply problems to each cell will intensify, the greater the number of cells in the stack. Due to variations in dimensional tolerances, the fuel flow will vary to each cell in the stack. It is likewise axiomatic that the more fuel cells a stack contains, the more electricity it will produce. Thus a considerable problem of adequate distribution of fuel can arise with a stack which contains, for example, five hundred fuel cells in it, which is a reasonable number of cells for a commercially viable stack to have.

For efficient operation of a stack, the cells should consume from 80 to 90% or more of the fuel supplied to them. Thus, by way of illustration, if one hundred moles of fuel is supplied to a stack, ideally 80 to 90 moles should be consumed by the stack leaving 10 to 20 moles of fuel to be exhausted from the stack. In the event that due to dimensional tolerances some of the cells will receive more than their desirable mole share, then less available fuel is left for the other cells in the stack. Should a cell in the stack consume all of the fuel available to it because of inadequate fuel supply caused by other cells receiving more than their share, then that cell can go to a negative state. This is due to a lack of hydrogen atoms resulting from the lack of available fuel for the oxidation reaction. Such a negative state cell will consume or corrode the materials of the cell and fail in a short period of time, thus causing failure of the stack.

The aforesaid fuel starvation and stack failure problem is magnified manyfold in the case of power utility size operations which produce megawatts of power and require concurrent operation of many stacks to produce such quantities of power. In the prior art, the feeding of the fuel to a multi-stack power plant has been accomplished in parallel fashion. For example, if the power plant has three stacks, each of which can utilize 100 moles of fuel, and each of which is to run at a 90% utilization rate, then 300 moles of fuel are needed to run the plant. The 300 moles of fuel are divided equally and fed in parallel fashion, 100 moles to each stack. With 90% utilization, each stack will produce a 10 mole depleted fuel exhaust. Thus each stack will only have a 10 mole cushion to ensure against individual cell fuel starvation, and potential stack failure.

Disclosure of Invention

The distribution system of this invention utilizes the same starting amount of fuel, operates the stacks at the same utilization rate, and produces the same depleted fuel concentration for the power plant as the aforesaid prior art, but ensures that there will be no chance for fuel cell failure due to fuel starvation. Using the distribution system of this invention, an individual stack will never be required to utilize more than the overall percent of the fuel utilized by the system, thus there will always be at least an excess fuel cushion to ensure that individual cell fuel starvation failure will not occur. In order to achieve the aforesaid result, the fuel is fed to the stacks at least partially in serial fashion, with the depleted fuel exhaust from one or more stacks being used as the fuel supply for one or more subsequent stacks in the system. The stacks can be fed in pure serial fashion one after another, or they can be fed in stages, partly in parallel fashion, and partly in serial fashion. In the latter format, less than all of the stacks will be initially fed equal proportions of the total fuel needed, and the partially depleted fuel exhausted by them will be combined and fed into one or more subsequent stacks. The partially depleted fuel exhausted by the initial stack or stacks in the series is fed directly into the subsequent stack or stacks in the series without any enrichment other than combining with other stack exhausts, if present.

It is, therefore, an object of this invention to provide a system for fueling multiple fuel cell stacks in a power plant which ensures that each cell in the plant will receive adequate fuel for proper functioning.

It is a further object of this invention to provide a system of the character described wherein an increased excess fuel cushion is provided to ensure that no cell will experience fuel starvation due to excessive consumption of fuel by other cells in the stack.

It is yet another object of this invention to provide a system of the character described which utilizes the depleted exhaust fuel from one or more stacks

as fuel for subsequent stacks.

It is an additional object of this invention to provide a system of the character described wherein fuel is fed serially through successive stacks in the power plant.

It is another object of this invention to provide a system of the character described wherein fuel is fed in parallel and serial fashion through stacks in the power plant.

It is yet an additional object of this invention to provide a system of the character described wherein the cell components can be made more economically due to relaxation of dimensional tolerances which results from utilization of the system.

These and other objects and advantages of the invention will become more readily apparent from the following detailed description of preferred embodiments thereof when taken in conjunction with the accompanying drawings in which:

Brief Description of Drawings

FIGURE 1 is a schematic block diagram illustrating the prior art system for feeding fuel to a multi-stack power plant;

FIGURE 2 is a block diagram similar to FIGURE 1 but showing a first preferred embodiment of a fuel feeding system for a multi-stack power plant which operates in accordance with this invention; and

FIGURE 3 is a block diagram similar to FIGURE 2 but showing a second embodiment of a feeding system operating in accordance with this invention.

Best Mode for Carrying Out the Invention

Referring now to FIGURE 1, there is shown in block diagram form a fuel feeding system for a multi-stack power plant which operates in accordance with the teachings of the prior art. The plant shown has a plurality of stacks as, for example, three. Each stack is allotted enough fuel so that it can operate at maximum efficiency by consuming 90% of that fuel allocation, or aliquot. For purposes of illustration, assume that each stack is allocated 100 moles of fuel and that it will utilize or consume 90 moles (90%) of that allocation. The total fuel thus fed into the three stacks shown would be 300 moles which is fed through the conduit 2. The 300 moles of fuel is divided into equal 100 mole portions which are fed individually into STACK 1, STACK 2, and STACK 3 via branch conduits 4, 6 and 8 respectively. With each stack utilizing 90% of its fuel allocation, 10 moles of fuel will be exhausted from each stack through exhaust conduits 10, 12 and 14. Thus the total fuel input is 300 moles, the total fuel consumption is 270 moles, and the total fuel exhausted is 30 moles, assuming a 90% utilization rate. Obviously, the consumption and exhaust figures will vary should the consumption rate be changed. With the parallel feed system, each stack has only a 10 mole cushion to use to guard against individual cell fuel starvation in the event of excessive percent fuel consumption due to low flow of fuel to one or more cells in a stack. This cushion could be increased by increasing the fuel allocated to each stack, however, such an approach would be wasteful of the fuel. In order to minimize the occurrence of cell fuel starvation when operating with such a small excess fuel cushion, cell and stack component specification tolerances become so tight that commercial impracticality of the power plant concept is markedly increased. It will be noted in FIGURE 1 that there may be other stacks in the system which will be fueled in a similar manner. It is understood that the 300 moles of fuel referred to above is merely the aliquot of the total fuel which is allotted to the stacks actually shown.

Referring now to FIGURE 2, there is shown a preferred fuel distribution system for three stacks which operates in accordance with this invention. The allotted three stacks aliquot of 300 moles of fuel is delivered to the stacks via the conduit 102. The 300 moles of fuel is divided into equal 150 mole shares, one of which is fed into STACK 1 through conduit 104 and the other of which is fed into STACK 2 through conduit 106. STACK 1 and STACK 2 operate at the 90 moles fuel consumption rate and thus each will consume about 90 moles of the 150 moles fed into it. Thus each stack will exhaust 60 moles into the exhaust conduits 110 and 112. This means that the fuel starvation cushion for each of STACK 1 and STACK 2 is 60 moles. STACK 1 and STACK 2, using the system shown in FIGURE 2 with the preferred 90 mole consumption rates will consume only 60% of the fuel fed into each of them. The two 60 mole exhausts from STACK 1 and STACK 2 are then combined in conduit 108 so that STACK 3 is fed 120 moles of fuel. STACK 3 operates at its preferred 90 mole consumption level thus consuming 90 of the 120 moles of fuel and exhausts the remaining 30 moles of fuel through conduit 114. Thus STACK 3 has a 30 mole fuel starvation cushion when operating at its preferred consumption level. It will be noted that STACK 3 will thus consume only 75% of the fuel fed into it. The system shown in FIGURE 2 thus feeds the same initial total fuel into the three stack power source, i.e. 300 moles, as that shown in FGURE 1, but in the FIGURE 2 system, each stack is provided with a much greater fuel starvation cushion during operation. This additional leeway is provided merely by properly arranging the feeding sequence and does not require any additional fuel enrichment anywhere in the system. With the additional fuel cushion provided by this system, manufacturing tolerances are significantly relaxed so that the concept of a multi-stack commercial utility power source becomes commercially viable. Dimensional tolerances do not need to be severe to ensure that all cells in the stack receive their reuqired share of total fuel available using the system of FIGURE 2 since during the feeding of each stack, there is ample extra fuel available to accommodate some cells using more than their ideal share. It will likewise be appreciated that additional stacks can be fed in a like manner. For example, a six stack power plant can be fed in a five to one parallel serial system, or, less preferred, in a three, two, one parallel serial system. It will be noted that the essence of the system shown in FIGURE 2 is that the exhausted fuel from all stacks except the terminal stack or stacks

adds to the fuel cushion available for any subsequent stacks. Such is not the case for the prior art system shown in FIGURE 1.

It will be appreciated that the system of this invention facilitates the fabrication of stacks in modular building block-type units which can be used to construct large multi-stack plants. When a system of stacks is fueled using this system, the percent of the fuel utilized by the last stack in the system will always be less than the overall utilization of the system, and can be calculated by the formula:

$U_L = U_{overall}/U_{overall} + N(100\text{-}U_{overall})$

wherein U_L is the percent of fuel utilized by the last stack in the system, $U_{overall}$ is the percent of fuel utilized by the total system and N is the number of stacks in the system.

Referring now to FIGURE 3, there is shown a second embodiment of the invention wherein the stacks are fed in purely serial fashion. The conduit 202 carries the requisite 300 moles of fuel, all of which is fed into STACK 1 via conduit 204. STACK 1 consumes its 90 mole portion of the fuel and exhausts 210 moles into STACK 2 through conduit 206. STACK 2 then consumes its 90 mole share of the 210 moles and exhausts 120 moles into STACK 3 through conduit 208. STACK 3 consumes its 90 mole share and exhausts 30 moles of the fuel through conduit 214. With the system shown in FIGURE 3, STACK 1 consumes 30% of the fuel fed into it, STACK 2 consumes 42.8% of the fuel fed into it, and STACK 3 consumes 75% of the fuel fed into it. As in each of the foregoing examples, the total fuel fed into the system is 300 moles and the total fuel exhausted from the system is 30 moles. The system shown in FIGURE 3, like that shown in FIGURE 2, allows fabrication of stack components with more relaxed dimensional tolerances due to the increased fuel cushion and thus is viable for use in a multi-stack commercial utility power plant.

The embodiment shown in FIGURE 2 is preferred over the embodiment of FIGURE 3 due to the fact that the former has fewer stages and thus requires less pressure to pump the fuel through the system, or for the same inlet pressure, results in lower pressure loss.

It will be readily appreciated that the system of this invention will greatly minimize or eliminate fuel cell stack failure in multi-stack power plants due to individual cell fuel starvation. The system provides these advantages without the need to increase fuel input or exhaust. Use of the system renders practical, commercial utility sized multi-stack power plants due to relaxation of manufacturing tolerances. The oxygen can be fed into the stacks serially or in parallel fashion.

Since many changes and variations of the disclosed embodiments of the invention may be made without departing from the inventive concept, it is not intended to limit the invention otherwise than as required by the appended claims.

Claims

1. In a multi-stack fuel cell power plant, a fueling system comprising:

a) a first power-generating stage including one or more fuel cell stacks;

b) a second power-generating stage including one or more fuel cell stacks;

c) means providing an amount of fuel to said system sufficient to operate all of the stacks in the system at a predetermined fuel utilization rate;

d) means for delivering all of said amount of fuel to said first stage for operation of the latter; and

e) means for delivering fuel exhausted from said first stage to said second stage for operation of the latter, said fuel exhausted from said first stage comprising more fuel than is necessary to operate said second stage at said predetermined fuel utilization rate.

2. In a mulit-stack fuel cell power plant, a fueling system comprising:

a) a first power-generating stage including one or more fuel cell stacks;

b) a second power-generating stage including one or more fuel cell stacks;

c) means providing an amount of fuel to said system sufficient to operate each of the stacks in the system with a predetermined aliquot of said amount of fuel;

d) means for delivering all of said amount of fuel to said first stage for operation of the latter; and

e) means for delivering fuel exhausted from said first stage to said second stage for operation of the latter, said fuel exhausted from said first stage comprising more fuel than the sum of said fuel aliqouts for each stack in said second stage whereby each stack in said second stage is protected against shutdown due to fuel starvation of its individual fuel cells.

3. In a multi-stack fuel cell power plant, a fueling system comprising:

a) a first power generating stage including a number of fuel cell stacks;

b) a second power generating stage including a number of fuel cell stacks which is less than the number of stacks in said first stage;

c) means providing an amount of fuel for said system sufficient to operate each of the stacks in the system with a predetermined aliquot of fuel;

d) means for delivering all of said amount of fuel in equal shares, each of which is larger than said predetermined aliquot, to each of said stacks to said first stage;

e) exhaust conduit means interconnecting said stacks in said first stage with said

stacks in said second stage, said exhaust conduit means being operable to combine fuel exhausted from said stacks in said first stage and deliver said combined fuel to the stacks in said second stage in equal shares which shares are larger than said predetermined aliquot of fuel whereby each stack in the system operates with a supply of fuel which is larger than said predetermined aliquot.

4. A multi-stack fuel cell power plant comprising:

a) a series of fuel cell stacks having an initial stack, one or more medial stacks and a final stack;

b) means providing an amount of fuel to said series of stacks sufficient to operate each of the stacks in the series with a predetermined aliquot of said amount of fuel;

c) means for feeding all of said amount of fuel to said initial stack;

d) means for feeding exhaust from said initial stack to one of said medial stacks and for feeding seriatim exhaust from one stack to another stack whereby each stack, save said initial stack, is fueled solely by exhaust from a preceding stack; and

e) wherein the exhaust from each stack, save said final stack, contains more fuel than said predetermined aliquot whereby said stack in the series operates with a supply of fuel which is larger than said predetermined aliquot.

5. A method of fueling a multi-stack fuel cell power plant, said method comprising the steps of:

a) providing a supply of fuel sufficient to furnish each stack in the plant with a predetermined aliquot of operating fuel;

b) feeding all of said supply of fuel into a first stage of the plant, which first stage includes one or more stacks; and

c) feeding exhaust fuel from said first stage into a second stage of the plant, which second stage includes one or more stacks whereby each stack in the plant is supplied with an amount of operating fuel which is greater than said predetermined aliquot.

6. The method of Claim 5 wherein said second stage has fewer stacks than said first stage.

7. The method of Claim 6 including the steps of combining the exhaust fuel from said stacks in said first stage and feeding said combined fuel to said one or more stacks in said second stage.

8. The method of Claim 5 wherein said first stage includes a plurality of stacks and said supply of fuel is divided into equal portions, each of which is fed into a stack in said first stage.

9. A method of fueling a multi-stack fuel cell power system having a plurality of fuel cell stacks, said method comprising the steps of feeding a first stage containing all of the stacks but one in the system with a parallel fuel feed arrangement whereby each stack in the first stage receives an equal share of the fuel needed to operate the entire system at a predetermined fuel utilization rate, and combining all of the fuel exhausted from the stacks in the first stage and fueling the remaining stack in the system with the combined exhaust fuel from the first stage.

10. A method of fueling a multi-stack fuel cell power system having a plurality of fuel cell stacks arranged in series to define a last stack in the series, comprising the steps of feeding fuel to the stacks in the system serially wherein fuel exhausted from some of the stacks is used to fuel others of the stacks subsequent in the series, and providing an amount of fuel to the last stack whereby the fuel utilization rate of the last stack is defined by the formula

$$U_L = U_{overall}/U_{overall} + N(100\text{-}U_{overall})$$

wherein U_L is the percent of fuel utilized by the last stack, $U_{overall}$ is the percent of fuel utilized by the entire system, and N is the number of stacks in the system.

FIG.1 PRIOR ART

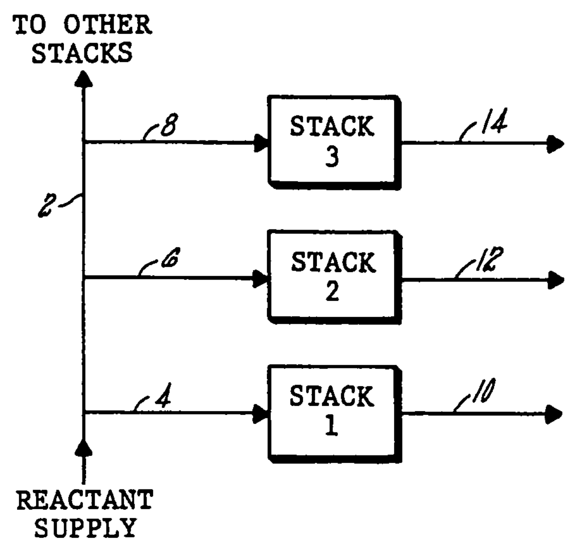
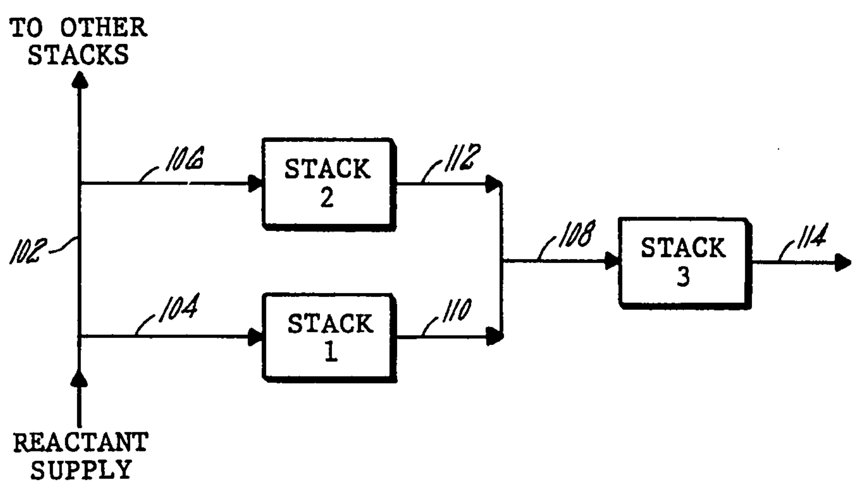


FIG.2



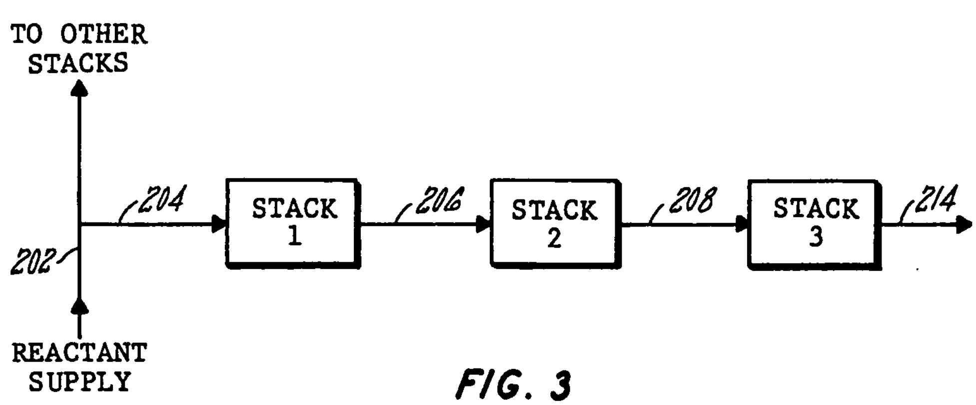


FIG. 3

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 87630163.1

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.4)
A	US - A - 3 711 333 (KOHLMULLER) * Abstract; fig. 1 * --	1,4,5	H 01 M 8/00 H 01 M 8/24
A	US - A - 3 668 011 (GRUNE et al.) * Claim 1; fig. * --	1,4,5	
A	US - A - 3 817 792 (SPAHRBIER) * Abstract; fig. 1 * --	1,4,5	
A	GB - A - 2 039 134 (INSTITUT FRANCAIS) * Claim 1 * ----	1,4,5	
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
			H 01 M

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	23-12-1987	LUX

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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